13th ICCRTS: C2 for Complex Endeavors

13th ICCRTS
'C2 for Complex Endeavors"
Enabling Adaptive C2 via Semantic Communication and Smart Push:
A Model-based Network Communication Approach
Topics: Networks and Networking

LtCol Carl Oros, USMC,
Naval Postgraduate School (Code 03M)
1 University Circle
Monterey, CA 93943
831-656-3386
cloros@nps.edu

Title of Paper
Enabling Adaptive C2 via Semantic Communication and Smart Push: A Model-based Network Communication Approach

Abstract
Fundamental to the concept of Network Centric Warfare lies the precept that shared awareness, collaboration, and self-synchronization can be attained through the networking of knowledgeable, geographically and hierarchically dispersed entities. The DoD GIG Architecture Vision is the prime policy directive chosen to realize this goal. Consistent with the tenants of NCW, the GIG architecture framework envisions highly responsive, agile, adaptable, and information-centric operations. These desirable net-centric attributes are prescribed to be implemented via a *Smart Pull* methodology. However, a pull architecture not only must contend with the demands of disseminating diverse, timely information to numerous entities, but more importantly it must address the cognitive bandwidth limitations inherent to users searching for, discovering, and pulling contextually relevant, mission critical information. This paper provides an alternative *operationalized* Model-based C2 network approach where entities share a dynamic model of the environment and information is smartly *Pushed* via VIRT services to relevant entities when user defined Conditions of Interest occur. Mission thread semantics are used to generate an ontology that supports a contextually rich data structure capable of supporting the information requirements of diverse actors and entities united in the endeavor.

Keywords: C2, VIRT, Model-based Communication Networks, semantic communication

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **JUN 2008**	2. REPORT TYPE	3. DATES COVERED **00-00-2008 to 00-00-2008**

4. TITLE AND SUBTITLE **Enabling Adaptive C2 via Semantic Communication and Smart Push: A Model-based Network Communication Approach**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Naval Postgraduate School,Code 03M,1 University Circle,Monterey,CA,93943**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

13th International Command and Control Research and Technology Symposia (ICCRTS 2008), 17-19 Jun 2008, Seattle, WA

14. ABSTRACT

Fundamental to the concept of Network Centric Warfare lies the precept that shared awareness, collaboration, and self-synchronization can be attained through the networking of knowledgeable, geographically and hierarchically dispersed entities. The DoD GIG Architecture Vision is the prime policy directive chosen to realize this goal. Consistent with the tenants of NCW, the GIG architecture framework envisions highly responsive, agile, adaptable, and information-centric operations. These desirable net-centric attributes are prescribed to be implemented via a Smart Pull methodology. However, a pull architecture not only must contend with the demands of disseminating diverse, timely information to numerous entities, but more importantly it must address the cognitive bandwidth limitations inherent to users searching for, discovering, and pulling contextually relevant, mission critical information. This paper provides an alternative operationalized Model-based C2 network approach where entities share a dynamic model of the environment and information is smartly Pushed via VIRT services to relevant entities when user defined Conditions of Interest occur. Mission thread semantics are used to generate an ontology that supports a contextually rich data structure capable of supporting the information requirements of diverse actors and entities united in the endeavor.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**38**	

Enabling Adaptive C2 via Semantic Communication and Smart Push: A Model-based Network Communication Approach

LtCol Carl Oros, USMC
Naval Postgraduate School
Monterey, CA 93943
cloros@nps.edu

Abstract

Fundamental to the concept of Network Centric Warfare lies the precept that shared awareness, collaboration, and self-synchronization can be attained through the networking of knowledgeable, geographically and hierarchically dispersed entities. The DoD GIG Architecture Vision is the prime policy directive chosen to realize this goal. Consistent with the tenets of NCW, the GIG architecture framework envisions highly responsive, agile, adaptable, and information-centric operations. These desirable net-centric attributes are prescribed to be implemented via a *Pull* methodology. However, a pull architecture not only must contend with the demands of disseminating diverse, timely information to numerous entities, but more importantly it must address the cognitive bandwidth limitations inherent to users searching for, discovering, and pulling contextually relevant, mission critical information. This paper provides an alternative *operationalized* Model-based C2 network approach where entities share a dynamic model of the environment and information is smartly *Pushed* via VIRT services to relevant entities when user defined Conditions of Interest occur. Mission thread semantics are used to generate an ontology that supports a contextually rich data structure capable of supporting the information requirements of diverse actors and entities united in the endeavor.

1. Introduction

Fundamental to the concept of Network Centric Warfare (NCW) lies the precept that shared awareness, collaboration, and self-synchronization can be attained through the networking of knowledgeable, geographically and hierarchically dispersed battlefield entities [1]. The DoD Global Information Grid (GIG) Architecture Vision [2] is the prime policy directive adopted to institute this goal. In concert with the tenants of NCW, the GIG architecture framework envisions highly responsive, agile, adaptable, and information-centric operations. The information exchange methodology proposed by the GIG architecture principally implements net-centric services via *Pull*, in concert with dynamic "Publish and Subscribe." This not only places extreme bandwidth demands on the architecture to disseminate diverse, timely information to numerous entities, but more importantly neglects the cognitive limitations users will face in finding and pulling contextually relevant, mission critical information. In fact the GIG architecture forecasts the need to capture, process, and store volumes of airborne and land based sensor net data "estimated to exceed exabytes (10^{18} bytes)" (GIG Vision, p.21). This paper provides an alternative *operationalized* Model-based C2 network approach where information is smartly *Pushed* (as apposed to "broadcasted") via Valuable Information at the Right Time (VIRT) services [3], [4], [5]. VIRT services function to push information to relevant entities when user defined Conditions of Interest (COIs) occur. A notional Marine Air-Ground Task Force (MAGTF) tactical scenario [6] was used to derive operational semantics and produce the resultant ontology. Ultimately, this mission thread serves to elucidate the operationally relevant "business logic" and to inform the future development of effective *Smart Push* Service Oriented Architecture (SOA) systems.

The approach presented in this paper is unique in that it (1) presents a *model-driven architecture* to share dynamic information, (2) incorporates an ontology derived from user defined semantics (i.e. bottom up) vice community determined (top down), and (3) *distributes* contextually meaningful information by design vice simply *transmitting* it via the network.

2. Towards Command and Control (C2) Agility

One of the major tenets of NCW holds that all battlespace entities will possess the ability to not only share distributed understanding, but more importantly to self-synchronize. These two universally accepted goal attributes are entrenched in the Command and Control Research Program (CCRP) literature. Put simply, synchronization refers to activities purposely organized in time and space [7]. The theory of NCW postulates that "empowered by knowledge, derived from a shared awareness of the battlespace and a shared understanding of commanders' intent, our forces will be able to self-synchronize, operate with a small footprint, and be more effective when operating autonomously. A knowledgeable force depends upon a steady diet of timely, accurate information, and the processing power, tools, and expertise necessary to put battlespace information into context and turn it into battlespace knowledge" [1]. Since the seminal works of Vice Adm. Arthur Cebrowski and Network Centric Warfare, the DoD CCRP has published several books building on this central net-centric theme. In *Power to the Edge* [8], the NCW maturity model represents the highest maturity level (level 4) as the C2 domain where shared awareness and self-synchronization are integrated. In *Planning Complex Endeavors* [7], the NATO Network Enabled Command and Control Maturity Model (N2C2M2) defines Agile C2 as a level of maturity characterized by a high degree of shared understanding of common (collective) intent, rich and continuous participant interactions, widespread information exchanges, and the willingness and ability (where appropriate) to self-synchronize. Thus there is literary consensus that shared awareness and self-synchronization constitute the requisite elements of agile C2. The challenge at hand is how to architect the "infostructure" [8] *(i.e., GIG)* to foster the emergence of these desired attributes.

2.1 Obstacles in the Path: *The Bandwidth Bottleneck*

Physical bandwidth is a limited resource and the dissemination of vast quantities of data will place extreme demands on the wireless network that is constrained and spectrum-confined. The Congressional Budget Office (CBO) study "*The Army's Bandwidth Bottleneck"* [9] detailed the impending bandwidth (BW) dilemma faced by the Army and recommended three potential mitigation strategies: (1) boost bandwidth by purchasing more high-bandwidth devices, (2) reduce demand, and (3) better manage the supply/demand mismatch. The Government Accounting Office (GAO) [10] reported that the US Army had plans to field 15 brigade-sized Future Combat System (FCS) units of action by 2020 at a cost of $92B (2004 dollars). The GAO report further stated that the BW demand was estimated to be 10 times greater than actually available. The reader should note that FCS is only one small portion of the Army's GIG requirement and does not at all address the Joint force's combined BW demands

Currently, the US military is operating numerous unmanned systems and is potentially moving to procure hundreds of networked, sensor-laden UAVs capable of video, communications, and electronic surveillance. Some of these systems will have the ability to collect tens of terabytes of data each hour. A recent *USA Today* article [11] reported that last year US military UAVs logged over 14,000 hours a month over hostile skies. If we assume 10 TB/hour x 14,000 hrs/month = 140 petabytes (10^{15} bytes)/month x 12 months = 1.68 exabytes per year of UAV data alone. The article further states that the USAF will spend $13B to purchase 241 drones in the next 5 years. Without an additional exponential increase in intelligence analysts and BW piping, it is hard to believe that even a small fraction of relevant, time-critical battlefield information will ever reach the operator who needs it the most.

2.2 Human Bandwidth and *InfoGlut*

The technological advances in networking technologies and computer processing power have created a phenomenon where computer-generated information vastly exceeds the human capacity to process it. Following Moore's Law, civilization is witnessing a doubling of computer performance every 18 months. Intel is currently migrating towards tera-scale computing where computer chips with hundreds of cores will perform trillions of operations each second [12]. Advances in data storage are also rapidly evolving. Today, one can purchase a terabyte (1TB) external hard drive for just over $200.00.

Though these advances provide tremendous technical capabilities, their less desirable tendency is to quickly inundate the humans who are confronted with the information. At the heart of the dilemma lies the fact that human bandwidth is a relatively fixed quantity. For example, my current Microsoft Outlook inbox receives approximately 50 to 100 e-mails per day, and

at present, contains over 5,200 items totaling 1.2GB of data. This may seem trivial to an intelligence officer or analyst whose in-box case load potentially exceeds this volume by orders of magnitude. This places an extreme info-load on the human who must process, assess, and distribute relevant and often time critical information to discrete users. Furthermore, advances in information technology (IT) processing, storage, and dissemination have only exacerbated the problem. This InfoGlut [13] has amounted to users "drowning in a sea of data and information while frequently lacking real knowledge" [14].

The infantryman has historically been weighed down by backpacks laden with *molecules (i.e. radios, batteries, ammo, armor, and sustenance)* in excess of 140 lbs. If technological trends continue, we will assuredly overload him with *bits* as well. Adopting a Smart Pull methodology places the information burden on the user who, amidst a sea of data, is constrained by limited cognitive BW, time stressed, and operating in extreme, hostile conditions. Given these conditions, the network must address the practical needs of the operator with a radically different architecture. That challenge is squarely addressed by using *Smart Push* in conjunction with a model-based communication network.

2.3 Smart Push Myths

The concept of *Smart Push* used in this paper is discussed within the framework of a model-based network (MCN) architecture. It assumes that all entities share a state-full, distributed, filtered model (collections of beliefs, assumptions, plans, etc.) describing the environment they are operating in. The models are never complete, perfect, or certain, but rather correspond to the best available characterizations of the battlefield situation obtainable in real-time. The networked entities are also aware of their peers' states and smartly push information of value to them when predefined conditions of interest (COIs) occur. In this way, the MCN entities effect a best-effort synchronization of distributed states of belief across the battlespace. Unfortunately, *Push* originated in a different context and has often been branded as undesirable by the net-centric literature. For example, *Power to the Edge* states that "we need to move from a push-oriented dissemination process to a pull-oriented one [for] this is the only way to satisfy the needs of a heterogeneous population of information users." And "the move from *smart push* to *post and smart pull* not only solves previously intractable problems by identifying important information and getting it to the right persons, but also facilitates the creation of interoperability." Even in *Planning Complex Endeavors,* the authors state that "individuals and organizations get [*are pushed*] the information that someone else *thinks* they need but not necessarily the information that they *do* need." As will soon be discussed, central to a MCN architecture are *user* defined information requirements, mutually agreed upon *semantics*, and a common *ontology* for man and machine interpretation. An MCN specifically nullifies the naïve concerns that "without an adequate understanding of the situation being faced by another entity, the entity in possession of the information cannot judge its potential value or urgency." To the contrary, the **distributed MCN model serves as the architecture's "kernel" and provides the state-full, contextual linkage between diverse entities united in purpose.**. The *Power to the Edge* authors also assert that it's a "very tall order for someone to be smart about who needs what. To extend the argument beyond one entity to a large organization, such as DoD, no single individual or small group of individuals can possibly know even a small fraction of the situations currently or potentially affecting people throughout the enterprise" (p. 76). Attaining this degree of requisite awareness certainly presents a significant social, technological, and organizational challenge. Relying on humans, networking, and niche applications alone does not address the fundamental desire to share situational awareness amongst a diverse set of actors and entities. However, as our beliefs, plans, and information needs become more accessible and machine interpretable, the computer has the potential to assume a more prominent role. For example, Intel is currently conducting research on multi-core processors that integrate machine learning algorithms and inference technology [12]. Microsoft's Adaptive Systems and Interaction Group are experimenting with Bayesian machine learning to predict surprises in Seattle's traffic system to alert drivers [15]. And in Iraq, soldiers conducting street patrols are using a Defense Advanced Research Project Agency (DARPA) collaborative software application that distributes dynamic tactical ground information to combat teams engaged in counter insurgency operations [16]. However, predictive algorithms and bandwidth hungry applications alone do not easily scale to GIG proportions. Ultimately, the *infostructure* must be responsive to the endeavor's diverse, complex, and dynamic information needs. Tremendous opportunities arise, however, when machines are architected to understand their client's needs, maintain state-full mission-awareness of collaborating entities, and can infer the impact of newly attained knowledge

and information on their battlefield peers. Given this perspective, *Smart Push* myths no longer seem valid.

3. Enabling Smart Push: A Model-based Communication Network Approach

Claude Shannon remarked in his 1948 *Mathematical Theory of Communication* [17] that "frequently messages have meaning" [and] "these semantic aspects of communication are irrelevant to the engineering problem" (p.1). Shannon was more concerned with decreasing the uncertainty in the channel; focusing mainly on the physical layer aspects of electronic communication. It would be another 35 years before the first TCP/IP wide area network would become operational [18], 46 years until the Open Systems Interconnection Basic Reference Model [19] was published, and 53 years before the conception of the World Wide Web Consortium's (W3C) Semantic Web [20]. Though Shannon's principles have been used in developing advanced coding techniques and protocols that have had a cumulative net positive effect of increasing the channel's bandwidth, the "engineering problem" for the most part has ignored the potential bandwidth (both cognitive and physical) that can be realized when the receiver and transmitter share a common model, context, and semantics. Fundamental to Shannon's theory is the notion of decreasing uncertainty at the receiver. Today this is typically achieved at the physical and data link layers of the OSI model. Upon successful receipt, the upper layer payload "data" is merely pushed up the stack and eventually reaches the human receiver where it must also be decoded, processed, edited, and disseminated. When actors and entities share a distributed model of battlespace situations, only the events that reduce uncertainty (i.e. information, corresponding to surprises or resolutions of unpredictable outcomes), need be transmitted. Transmission of these informative "deltas" from current belief can also potentially reduce bandwidth by orders of magnitude [4]. The bits corresponding to these deltas are meaningful to the operator, because they characterize changes in receiver beliefs. Per force, they speak the language of the receiver.

Thus transmitting meaningful bits has the added benefit of not only reducing the medium's BW requirements, but it also addresses the operator's cognitive BW limitations by only transmitting valuable information. The information is potentially valuable to the receiver because it reduces errors in the receiver's situation model. Error corrections that the receiver would deem insignificant or irrelevant should not even be communicated To use a trivial example, imagine the difference between processing streaming video and voice commentary of the events leading up to the April 1775 indications and warnings of *"the British are coming"* vice transmitting one *bit* via steeple-based lanterns. Valuable, meaningful, uncertainty-reducing communication reduces in this case Gigabytes to a single bit. This is the ethos of an MCN. A shared distributed model of the operational environment forms the communication core. This core "world model" is contextually derived from operator semantics, because it need convey only those meaningful distinctions the operator values.

VIRT services monitor for changes to this core model in addition to pushing satisfied operator queries ("conditions of interest", COIs). Implementing an MCN mitigates uncertainty in two areas: (1) the physical channel (Shannon) and (2) the cognitive domain. NCO will require a robust network to purvey bits between mobile entities. Undoubtedly, the preponderance of this network will be wireless and void of fixed infrastructure. Maximizing the channel capacity at the OSI physical layer will remain crucial to ensuring *meaningful* bits make it to their destined entity. MCN entities in receipt of semantically rich, valuable bits, will incur the additional benefit of enhanced situational awareness, thereby decreasing uncertainty beyond OSI Layer 7.

The bandwidth-hungry GIG and FCS examples cited above highlight the limitations and challenges of distributing voluminous, dynamic information to a diverse group of operators. Distilling our architectural view of network communication to simply moving bits in the channel ignores the potential power and BW savings of communicating meaning. Even though Paul Revere's Old North Steeple lanterns "resolved the uncertainty to a binary choice, [they] conveyed a vast amount of meaning" [21]. The transmission of smart bits is made possible when entities agree on the information that is important to them (semantics) and are aware of the information needs of their peers.

3.1 MCN Defined

By definition, a "Model-based Communication Network is a state-full distributed system of collaborating nodes that maintains an optimal shared understanding of the situation. The situation at each node is composed of models of all entities relevant to its mission" [4]. This also enables each entity to dynamically project the future states of its peers. The

model is central to the MCN network and consists of the state-full, distributed, representation of actor's beliefs, assumptions, and plans, in the context of the operating environment. The model is not meant to be predictive. Rather, the term model implies a 4-dimensional instantiation of the entity's current, expected, and forecast mission states as a function of command intent, assumptions, perceptions, tasks, actions, interactions (friendly, enemy, environment), outcomes, constraints, restraints, etc. As a collective endeavor, all entities share this distributed model so as conditions occur that invalidate plan beliefs and assumptions, the requisite information is passed to the entities who value the information. The distributed model is then updated and the process continues.

In reality, this is no different than how the military operates today. In current practice however, the model is principally distributed through stove-piped systems and applications and ultimately depends on the operator's mental storage and retrieval during execution. Currently, there are no distributed systems that truly enable the operator to carry the plan into battle. All that remains of the plan when the infantryman crosses the line of departure, or the pilot climbs into his aircraft, is what's scribbled on a five paragraph order, annotated on a knee board card, or punched into a navigation system as waypoints. It is no wonder why the Microsoft Office disseminated plan never survives the first shot.

Simply networking heterogeneous entities is an insufficient guarantor of shared awareness. Filtering information by value provides a method for ensuring critical information flows between time stressed entities.

3.2 VIRT Services

The principle behind VIRT is to improve time-stressed collaborative decision making by distributing information that operators deem valuable to them in the context of their mission or task. VIRT adopts a *Smart Push* methodology that seeks out significant event occurrences among dynamic data sources in order to alert the operator/entity of conditions of interest deemed valuable to him.

Mission-based semantics fulfill two primary roles. First, they form the contextual information foundation from which the distributed model is architected. Secondly, they ensure that the associated ontology supports diverse, dynamic, state-full queries that each entity has deemed valuable. VIRT services continually monitor for these conditions and not only push information of value, but filter low priority bits as well. Unlike traditional databases that query historical data, the MCN distributed model is envisioned as state-full and capable of supporting queries into the past, present, or *future*. In fact, **future conditions** that appear to be unfolding in a predictable way often represent the best opportunities to exploit information advantage. Past states have already happened, and current conditions rapidly flow into states gone by, states beyond the range of our influence.

The following notional MAGTF High Value Target (HVT) mission thread illustrates the principles of an MCN-VIRT architecture.

4. An Operational Example

A notional HVT mission thread was used to elicit end user information requirements and develop a better understanding of the associated mission relevant semantics. For simplicity, the scenario consisted of a Platoon Commander maneuvering three squads during the conduct of a HVT raid mission. The notional mission spanned three phases: (1) Crossing the Line of Departure (LOD), (2) Ingress, and (3) Actions on Objective. Two Marine Officers [22] (graduate students in the JC4I Master's curriculum) were interviewed. The complete list of the information requirements gathered in the scenario-driven interview appears in Appendix A. It should be noted that this work was preliminary and the information requirements obtained were limited to the Platoon Commander perspective. A rich ontology should ideally capture the diverse semantics of various actor perspectives. Therefore, Platoon Sergeant, Fire Team leader, Pilot, Forward Air Controller (FAC), and Mission Commander all represent relevant groups for further study. It is the author's intent to focus future research in this area. Figure 1 depicts the notional HVT raid scenario that was used to obtain the information requirements.

4.1 Ontology Development

The collection of information requirements generated from the HVT mission thread informed the creation of an ontology that supported the end user's tactical information needs. Semantic concepts such as *Mission, Phase, Unit, Target*, were created that defined the contextual boundaries of the operational space. Additionally, these semantic mission order concepts remain broadly applicable to a diverse set of peer

actors/entities outside of the HVT mission space. Only the individual entity class attributes and actual object mission-instances render their uniqueness.

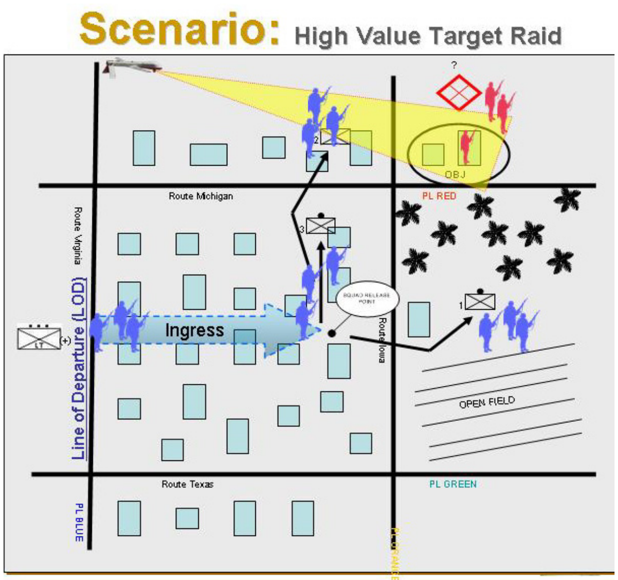


Figure 1. Notional MAGTF MCN-VIRT scenario

4.2 Semantic Object Modeling

The database design tool *Table Designer* [23] was used to illustrate the mission thread's ontological framework. Figure 2 depicts the resultant Semantic Object Model (SOM). Kroenke defines SOM as the constructs and conventions used to create a model of the user's data, whereby semantic objects represent "things" in a user's world he considers important. A semantic object is more formally defined as a "named collection of attributes that sufficiently describe a distinct entity" [24]. In this example, the resultant SOM is a contextual data model that reflects the operational context of the platoon commander's mission space and supports the flow of his critical information requirements.

In addition to single and multi-value attributes, an object can be simple (single values), can contain composite objects (simple or group attributes but no object attributes), or may consist of compound objects that contain one or more object attributes. For example, the *Table of Equipment* object consists of several simple attributes and a group attribute (*Unit*). The *Mission* object is a compound object, containing the objects*: Objective, Phase, Location, Platoon, Time, Targ*et, and *C2 Node*. Though this model is strictly illustrative, similar semantic models have been developed, like the *Maritime Information Exchange Model (MIEM)* [25] that adopt XML schemas, syntax, and embedded objects to share critical, dynamic intelligence information. For the ontology to be successful it must reflect the environment that actors /entities operate in and support their diverse critical information needs.

4.3 Actor (Human) Information Requirements

Information requirements that were deemed to be of critical value to the Platoon Commander, were classified as *Conditions of Interest* (COIs). COIs represent information that invalidates user plans, assumptions, go-no-go criteria, or is particularly urgent in nature and tethered to mission success. These COIs represent stateful queries that the ontology must be capable of supporting. VIRT services monitor for these conditions to be satisfied and when they are, smartly push the data of the satisfied query to the operator who values it. A few of the Platoon Commander's COIs are provided below:

- *Notify me if the target location is not as planned or expected.*
- *Notify me if my squad locations are not as planned or expected.*
- *Alert me if I am training my weapon system on a blue force member.*

The Platoon Commander does not require a steady stream of target location data or friendly Position Location Information (PLI) to provide him the situational awareness (SA) he desires. Rather, he needs to know when his assumptions are invalidated. When all actors/entities share the same model, and the user's COIs are translated into machine interpretable information, VIRT services push the satisfied queries to them. Thus VIRT services are *Shannon-like* in that predictable bits that represent nothing new are filtered out while valuable bits are transmitted. Transmitting only the information essential to understanding [26] presents two value adding benefits: (1) filtering out irrelevant bits increases the channel capacity (bandwidth) and (2) promotes a reduction of uncertainty at the cognitive level through the exchange of meaningful information.

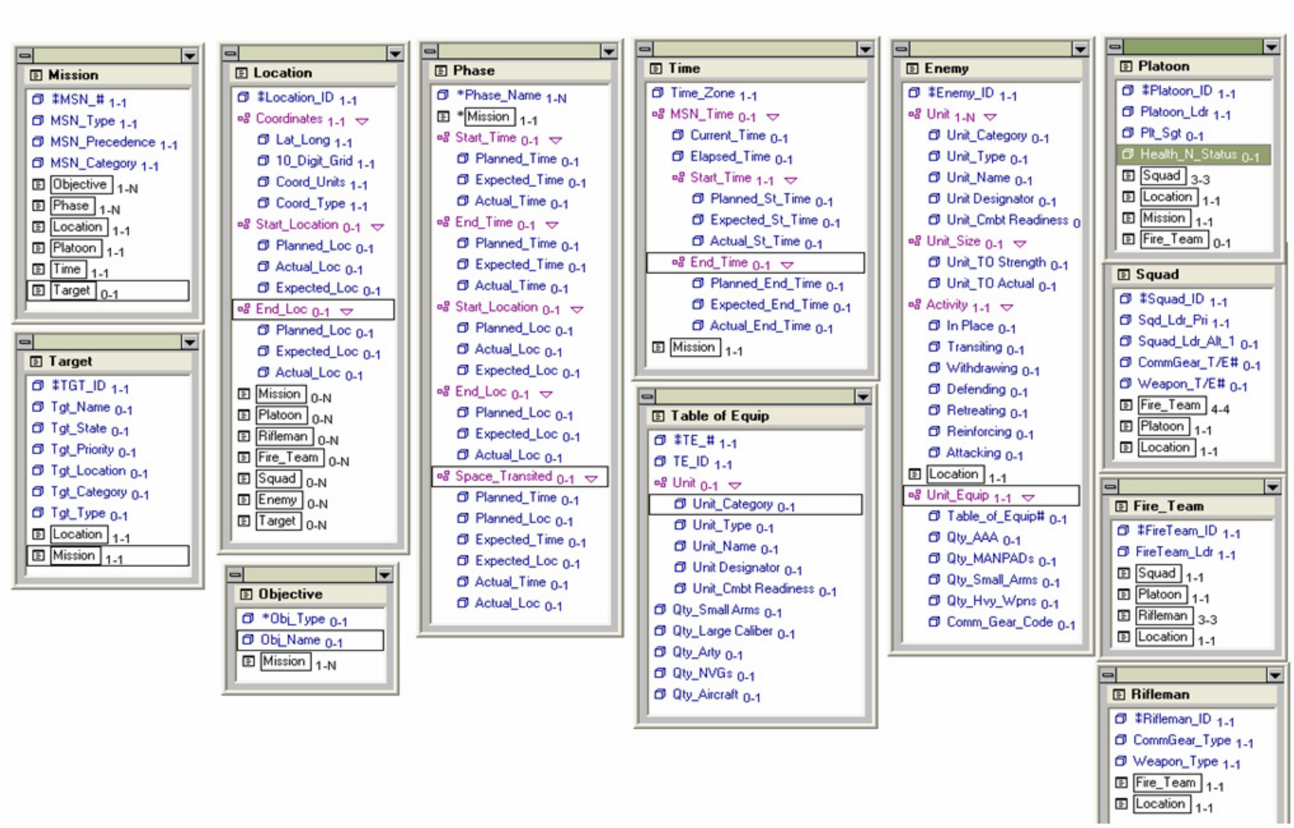


Figure 2. Portion of MAGTF-VIRT Semantic Object Model

Tables 1-3 provide examples of how the platoon Commander's meaningful information was translated into machine readable COIs.[1] For example, COI-1 is based on a planning assumption that the target location was known. Though this information was accurate during the planning phase there is no guarantee the target location will remain valid during mission execution. If the target location does not change, there is no information to be transmitted. The Platoon Commander wants to know when this assumption is negated. This serves as the trigger for the information flow.

Table 1: Target Location Condition of Interest

COI-1	*Notify me if the target location is no longer valid.*
Plan Assumption	Target Location is Known
Negated Assumption	Actual Target Location is not as planned or expected
Resulting VIRT Query	
[Mission]:Msn_#, Msn_Type-HVT, [Phase]= Ingress, [Target]:Tgt_ID, [Location]: Location_ID, Coordinates ≠ Coordinates Planned	

Table 2: Squad Location Condition of Interest

COI-2	*Notify me if my squad locations are not as planned or expected*
Plan Assumption	Squad locations are as planned or as expected
Negated Assumption	Squad locations are not as planned or expected
Resulting VIRT Query	
[Mission]: Msn_#, Msn_Type-HVT[Phase]= Ingress, [Squad] Squad_ID, [Location] Location_ID, Coordinates ≠ Coordinates Planned	

[1] The resultant VIRT queries in tables 1-3 are conceptual and merely express the process via pseudo code and do not imply specific software/database syntax.

Table 3: Fratricide Condition of Interest

COI-3	***Alert me if I am training my weapon system on a blue force member***
Plan Assumption	*Blue force organic weapons will not target blue forces*
Negated Assumption	*Blue force member is being targeted by a blue weapon system*
Resulting VIRT Query	
[Mission]:Msn_#, Msn_Type-HVT, [Phase]=All, [Target]:Tgt_ID, TGT_Location, = [Unit]_ID, Unit_Location ** where Unit = Squad/Fire-team/rifleman*	

4.4 Entity (Machine) Information Requirements

Although the examples above principally represent tactical, human-centric COIs, the semantics can also represent the critical information requirements of machine-based entities (i.e. C4ISR sensors, weapons systems, network management, etc.) as well.

Implicit to the NCW tenets is the intrinsic bond that exists between the network and the warrior. Future combat will depend upon the network to deliver actionable information to a diverse set of geographically dispersed actors and entities. This will require adaptive management of the bandwidth constrained network. In this vein, semantic reasoning for adaptive network management [27] is appropriate as well. An architecture that adopts such an "8th Layer" approach ensures the network is not only aware of its recipients, but it can also allocate its limited resources to guarantee delivery of valuable information [28].

Example "8th layer" network aware COIs might include:

- *What is the current/expected/forecast tactical network topology?*
- *What and where are the mission critical C2 nodes?*
- *Alert "me" when any critical C2 nodes have impending power/hardware/software failures.*
- *Alert "me" if peer node transmission packet loss exceeds "x" %,*
- *Do any adjacent nodes have available CPU processing time available?*
- *Notify "me" when I am approaching my C2 device's communication/reception threshold [as function of bandwidth/RSSI/Signal Correlation/SNR, etc.].*

Similar to the HVT ontology above, the network management COIs associated with the mission can also be supported by VIRT services focusing on machine-to-machine level information exchange. Today, much of this information is localized to the individual device's Management Information Base (MIB) data that is *centrally* managed.

Figure 3 depicts three additional Network Management objects added to the original HVT SOM. Note that *C2 Node* object is a compound object that contains the *Mission, Security, and Network Policy* objects as well. Though not exhaustive, they serve to illustrate that the network entities are also integral to the mission space. They further demonstrate that machine interpretable semantics can support the endeavor's distributed, semi-autonomous network operation center (NOC) management behavior.

Adopting an MCN architecture approach addresses many sub-problems associated dynamically networking diverse actors and entities. First, model-based communication approach incorporates a distributed meaningful model by design. The ontology is driven by user defined semantics and the role of VIRT services is to supply battlefield operators with timely information contextually relevant to the mission task. This approach, however, is not limited to the tactical information needs of the operators. Network management and information assurance (IA) COIs can also be addressed by the MCN approach. In fact, the network management and security aspects take on new meaning when they become embedded in the 4-D contextual mission space. For example, in the future it may be beneficial to dynamically identify, manage, and protect the critical nodes involved in prioritized missions rather than attempt to defend the whole network. As network nodes begin to proliferate network managers will quickly become overwhelmed. Traditional approaches to network operations center management will need to be reexamined. The MCN approach aptly addresses these issues when network and IA conditions of interest are incorporated within the model.

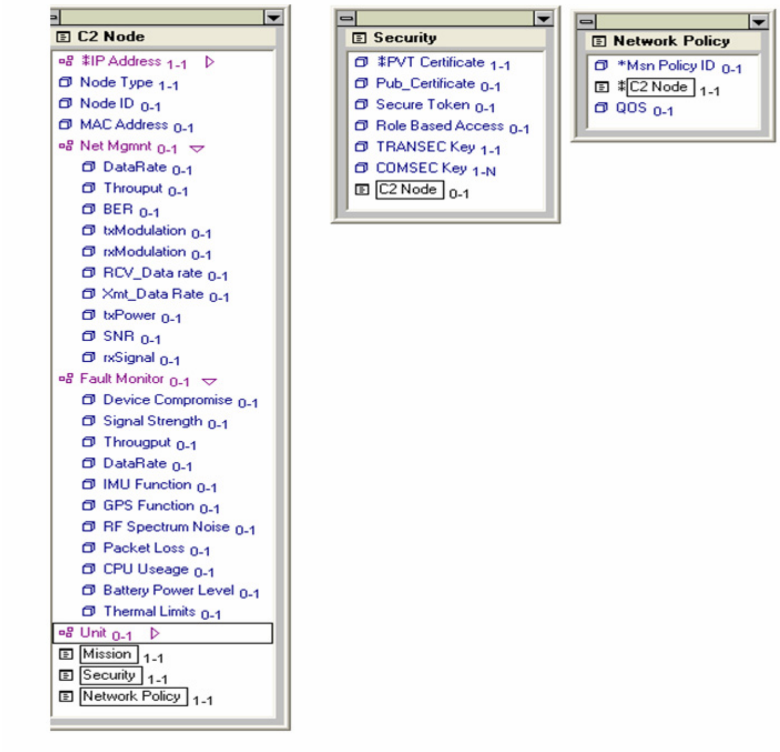


Figure 3: Network Management SOM

5. Summary and Conclusion

This paper provides an operationally grounded example of how implementing semantic tactical communication can promote adaptive C2. Shared awareness and understanding are desirable attributes of an agile C2 system. The NCW challenge is to distribute these attributes within the constraints of both human and system bandwidth. At the core of the MCN lies a semantic, dynamically updated, state-aware model of our plans, assumptions, beliefs, and mission critical information. Why is this vitally important?

- It addresses physical bandwidth limitation realities by the necessity to only transmit the "deltas" of the models, or the dynamic information that users really care about.
- MCNs mitigate *InfoGlut* by design because the ontology is semantically constructed to communicate meaningful, valuable bits.
- This addresses a diverse set of user information needs, spanning from the tactical, operational, & strategic operators and the assets they depend on (i.e. C4ISR platforms, network C2 nodes) to the networks their contextual bits ride upon (network managers, and network security professionals).
- MCNs promote C2 agility by providing entities a distributed, dynamically updated "kernel" of stateful knowledge essential to sharing awareness and a necessary precursor to self-synchronization.

Shannon believed that semantics was not part of the engineering problem. However, central to his work was the concept of transmitting the minimal amount of bits capable of reducing the receiver's uncertainty. Shannon, however, is not enough. The information processing and transmission capability of today's computer-based tactical systems not only exceed the network's channel capacity but they vastly surpass the human's cognitive information processing capability. It is in this emergent niche that an MCN becomes vital. Rather than solely strive to decrease uncertainty at OSI Layer 1 and 2, an MCN addresses uncertainty beyond Layer 7. As in Shannon's approach, only unpredictable information is transmitted. This is achieved by distributing a dynamically updated, shared model and implementing VIRT services that monitor for operator conditions of interest to emerge. This not only relegates critical information transfer to the

"deltas" of the models (minimizing physical BW), it also addresses the user's cognitive BW limitations by only transmitting meaningful, contextually relevant, user-valued *bits*. A common ontology derived from user semantics promotes shared awareness among diverse actors and when rendered machine readable, has the potential of yielding a highly agile and adaptive C2 system.

It is hypothesized that iterating this approach across diverse mission threads and perspectives will result in a rich ontology capable of supporting the critical information needs of time stressed, bandwidth deprived, tactical operators. Future work is needed, however, to design the dynamic database structures, integrate mission thread ontologies, develop scalable and robust network transmission media and protocols, and integrate information engineering strategies to eliminate system heterogeneity in our combat infostructure. Furthermore, DoD/Industry should adopt an incremental design approach to NCO/GIG development. The complexity of large scale engineering projects like the GIG, FORCEnet, and FCS, dictate a fresh, non traditional approach. "A significant part of the development must evolve through a robust experimentation process where new designs can be quickly and efficiently evaluated in an integrated environment with emphasis on human systems interfaces" [29]. It is time to move the architectures out of the PowerPoint domain and into the field where they can be experimentally evaluated, iterated, and given to the tactical operators who require them most.

6. References

[1] Alberts, D.S., J. J. Garstka, and F. P. Stein. *Network Centric Warfare: Developing and Leveraging Information Superiority*, DoD Command and Control Research Program, 2d edition, 1999.

[2] *Department of Defense Global Information Grid Architecture Vision: Vision for a Net-Centric, Service-Oriented DoD Enterprise*, Version 1.0, June 2007.

[3] Hayes-Roth, F. Model-*Based Communication Networks and VIRT: Filtering Information by Value to I Improve Collaborative Decision-Making*. 10th International Command and Control Research and Technology Symposium, McLean VA, 2005.

[4] Hayes-Roth, F. *Model-Based Communication Networks and VIRT: Orders of Magnitude Better for Information Superiority*, Command and Control Research and Technology Symposium, McLean VA, 2005.

[5] Hayes-Roth, F. *Two Theories of Process Design for Information Superiority: Smart Pull vs. Smart Push.* 2006 Command and Control Research and Technology Symposium, San Diego, CA, 2006.

[6] Oros, Carl, J. Scharlat, and C. Tsirlis, *Development of a VIRT Enabled Ground Mission Thread: MAGTF_VIRT*, World Wide Consortium of the Grid (W2COG) VIRT Working Group Brief, November 2006.
[7] Alberts, D. S., R. E. Hayes. *Planning: Complex Endeavors*, DoD Command and Control Research Program, 2007.

[8] Alberts, D. S., R. E. Hayes. *Power to the Edge: Command and Control in the Information Age*, DoD Command and Control Research Program, 2005.

[9] Congressional Budget Office Study, *The Army's Bandwidth Bottleneck*, The Congress of the United States, Congressional Budget Office, August, 2003.

[10] General Accounting Office (GAO) Report, Defense Acquisitions: *The Army's Future Combat Systems' Features, Risks, and Alternatives*, Paul L. Francis, Director Acquisition and Sourcing Management, Testimony before the Subcommittee on Tactical Air and Land Forces, Committee on Armed Services, House of Representatives, GAO-04-635T, 1 April 2004.

[11] "Drone Aircraft Use Triggers Power Struggle," AP, USA Today. 2007. Online; available: http://www.usatoday.com/news/washington/2007-07-05-unmanned-aircraft_N.htm.

[12] Greene, K., *The Future of Computing, According to Intel. Massively Multicore Processors Will Enable Smarter Computers that can Infer Our Activities*, MIT Technology Review, September, 2007. Online; available: http://www.technologyreview.com/Biztech/19432/

[13] Denning, P. J. The *Profession of IT: InfoGlut*, Communications of the ACM, July Vol. 49, No. 7, 2006.

[14] Gersh, J. R, J. A. McKneely, and R. W. Remington. *Cognitive Engineering: Understanding Human Interaction with Complex Systems*, Johns Hopkins Applied Physics Lab, Technical Digest, Vol. 26. No. 4, 2005.

[15] Waldrop, M. M. TR10: Modeling Surprise. Technology Review, March/April, 2008. Online; http://www.technologyreview.com/read_article.aspx?ch=specialsections&sc=emerging08&id=20243

[16] Talbot, D.. A Technology Surges.2008. Technology Review, March/April, 2008. Online: https://www.technologyreview.com/Infotech/20202/

[17] Shannon, C. E., *A Mathematical Theory of*

Communication, The Bell System Technical Journal, Vol. 27, pp.379-423, 623-656, July, October, 1948. Available http://plan9.bell-labs.com/cm/ms/what/shannonday/shannon1948.pdf

[18] On January 1st, 1983 the first TCP/IP wide area network became operational, when the United States' National Science Foundation (NSF) constructed a university network backbone that would later become the NSFNet. Source: http://www.historicaltextarchive.com/s/history-of-the-internet.php

[19] Information Technology –Open Systems Interconnection (OSI) – Basic reference Model: The Basic Model, International Standard, ISO/IEC 7498-1, 2d edition, Nov 1994.

[20] Berners-Lee, T., J. Hendler, and O. Lassila. *The Semantic Web*, Scientific American, May 2001, Available: http://www.sciam.com/article.cfm?id=the-semantic-web&print=true

[21] Miller, J. G.. 1978., *Living Systems*, McGraw Hill, NJ.

[22] The author taught a directed study course to two Marine officer graduate students in the JC4I curriculum at the Naval Postgraduate School in 2006. One officer was a prior enlisted heavy weapons Platoon Sergeant and after commissioning served as a Platoon Commander and Communications officer in combat operations in support of Operation Iraqi Freedom. Officer #2 was an experienced assault support helicopter pilot who had flown extensively in OIF.

[23] Table Designer is a semantic object modeling software tool developed by Dr. David M. Kroenke and is available for download at: www.tabledesigner.com/som.htm. It should be noted that this tool was used strictly for visual modeling only of the semantic object model. The output of table designer is a Microsoft Access or Sequel database. These database archetypes are incapable of supporting the dynamic, state-full, information storage and query requirements essential to creating a MCN-VIRT architecture. More research is needed in this critical area before MCN can come to fruition.

[24] Kroenke, D. M. *Database Processing: Fundamentals, Design, and Implementation*, 8th edition, Prentice Hall, 2001.

[25] Dunne, J., F. Hayes-Roth, K. Ligozio, D.Reading, and G. Small. *The Maritime Information Exchange Model (MIEM)*, Fusion 2008 Conference, 2008. (To Appear).

[26] "*Bell Labs Celebrates 50 Years of Information Theory: An Overview of Information Theory*", Accessed March 2008, Available from www1.alcatel-lucent.com

[27] Hoag, J. C. and F. Hayes-Roth. *Semantic Reasoning for Adaptive Network Management of Telecommunication Networks*, 2006 IEEE International Conference on Systems, Man, and Cybernetics, Proceedings, Vol 1, October 2006, Taipei, Taiwan.

[28] Bordetsky, A.; F. Hayes-Roth. *Extending the OSI model for wireless Battlefield networks: a design approach to the 8th Layer for tactical hyper-nodes*, International Journal of Mobile Network Design and Innovation, Vol 2, No. 2, 2007.

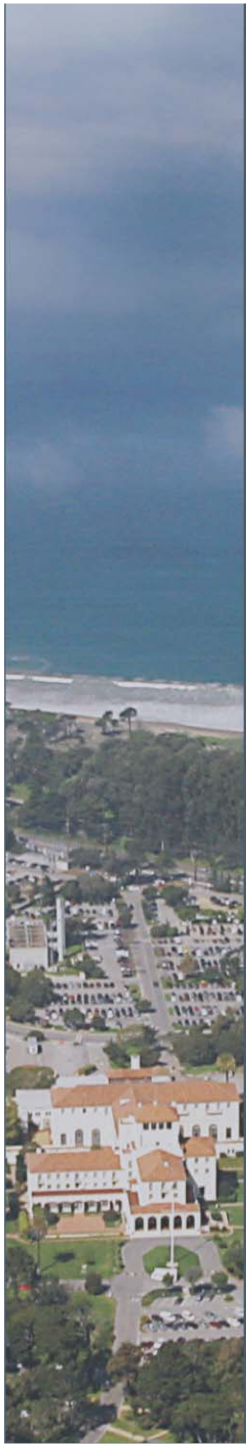
[29] Bar Yam, Y., *Large Scale Engineering and Evolutionary Change: Useful Concepts for Implementation of FORCEnet*, Report: F30602-02-C-0158, New England Complex Systems Institute, 2002.

Appendix A
HVT Information Requirements

SubType	Phase		Information Requirements During Line of Departure Phase
Red	LOD_1.0		//Target Location has changed//
		1	Current HVT_ID# location not as planned
		2	Current HVT_ID# location not as expected
		3	HVT_ID# location Unknown.
Blue	LOD_2.0		Health & status of organic, mission assigned, friendly forces
		1	Blue organic force member is seriously injured
		2	# of organic blue forces injured exceeds mission Go-No-Go criteria
Blue	LOD_3.0		//Location of msn essential organic blue force maneuver elements, in this case a 12 man squad.//
		1	Actual position of Squad(n) is not as planned
		2	Actual position of Squad(n) is not as expected
Blue	LOD_4.0		//Status of organic blue force critical weapon systems//
		1	# of critical organic blue force weapon systems nonoperational exceeds Go-No-Go criteria.
Blue	LOD_5.0		//Communication device effective range limt being reached//
		1	Organic blue force member's peer to peer com device approaching link range limit.
		2	Organic blue force member's peer to peer com device has exceeded effective com link range limit.
Blue	LOD_6.0		//Communication device approaching voice/video/data threshold capability
		1	Comm device data throughput [data rate?] approaching video threshold
		2	Comm device data throughput [data rate?] approaching data threshold
		3	Comm device data throughput [data rate?] approaching voice threshold
Blue	LOD_7.0		//Comm system's power available exceeded//
		1	Comm device power available threshold exceeded
Blue	LOD_8.0		//Enemy size has changed//
		1	Current enemy size not as planned
		2	Current enemy size not as expected
Red	LOD_9.0		//Enemy unit's weapon system employed has changed.//
		1	Enemy unit's weapon system not as planned
		2	Enemy unit's weapon system not as expected
Red	LOD_10.0		//Enemy unit's C4ISR capability//
		1	Enemy unit's ISR capability not as planned
		2	Enemy units's C2 capability not as planned
Red	LOD_11.0		//enemy RF communications threshold status used as an indicator and warning (I&W)//
		1	Enemy unit comm traffic exceeds normal parameters
Blue	LOD_12.0		//Position/status of blue force recon element//
		1	Blue force organic recon element (n) current position not as planned
		2	Blue force organic recon element (n) current position not as expected
		3	Blue force organic recon element(n) position comprimised
Blue	LOD_13.0		//Position/status of assigned blue force UAV//
Tgt	LOD_14.0		//Status of pre-planned target validity//
		1	Preplanned target (n) no longer valid
Blue	LOD_15.0		//Mission Abort status//
		1	Mission Commander receives abort order
Blue	LOD_16.0		//Fratricide alert capability//
		1	My weapons system is targeting a Blue force unit/member
		2	My weapon system's effects will have lethal impact on a Blue force unit/member
Blue	LOD_17.0		//Indiviual Blue force notification of potential fratricide danger//
		1	I am being targeted by a blue force weapon system
		2	I am in the casualty radius of a Blue force weapon system.

Subtype	Phase		Information Requirements During Ingress Phase
Red	In_1.0		//Target Location has changed//
		1	Current target location not as planned
		2	Current target location not as expected
Blue	In_2.0		Health & status of organic, mission assigned, friendly forces
		1	Blue organic force member is seriously injured
		2	# of organic blue forces injured exceeds mission Go-No-Go criteria
Blue	In_3.0		//Location of msn essential organic blue force maneuver elements, in this case a 12 man squad.//
		1	Current position of Squad(n) is not as planned
		2	Current position of Squad(n) is not as expected
Blue	In_4.0		//Status of organic blue force critical weapon systems//
		1	# of critical organic blue force weapon systems nonoperational exceeds Go-No-Go criteria.
Blue	In_5.0		//Communication device effective range limit being reached//
		1	Organic blue force member's peer to peer com device approaching link range limit.
		2	Organic blue force member's peer to peer com device has exceeded effective com link range limit.
Blue	In_6.0		//Communication device approaching voice/video/data threshold capability
		1	Comm device data throughput [data rate?] approaching video threshold
		2	Comm device data throughput [data rate?] approaching data threshold
		3	Comm device data throughput [data rate?] approaching voice threshold
Blue	In_7.0		//Comm system's power available exceeded//
		1	Comm device power available threshold exceeded
Blue	In_8.0		//Enemy size has changed//
		1	Current enemy size not as planned
		2	Current enemy size not as expected
Red	In_9.0		//Enemy unit's weapon system employed has changed.//
		1	Enemy unit's weapon system not as planned
		2	Enemy unit's weapon system not as expected
Red	In_10.0		//Enemy unit's C4ISR capability//
		1	Enemy unit's ISR capability not as planned
		2	Enemy unit's C2 capability not as planned
Red	In_11.0		//enemy RF communications threshold status used as an indicator and warning (I&W)//
		1	Enemy unit comm traffic exceeds normal parameters
Blue	In_12.0		//Position/status of blue force recon element//
		1	Blue force organic recon element (n) current position not as planned
		2	Blue force organic recon element (n) current position not as expected
Blue	In_13.0		//Position/status of assigned blue force UAV//
			??
Tgt	In_14.0		//Status of pre-planned target validity//
		1	Preplanned target (n) no longer valid
Blue	In_15.0		//Mission Abort status//
		1	Mission Commander receives abort order
Blue	In_16.0		//Fratricide alert capability//
		1	My weapons system is targeting a Blue force unit/member
		2	My weapon system's effects will have lethal impact on a Blue force unit/member
Blue	In_17.0		//Individual Blue force notification of potential fratricide danger//
		1	I am being targeted by a blue force weapon system
		2	I am in the casualty radius of a Blue force weapon system.
Blue	In_18.0		//Blue adjacent forces are engaged with the enemy//
		1	Blue adjacent forces engaged
Blue	In_19.0		//Mission has been compromised//
		1	Blue force organic recon element(n) position compromised
		2	Organic Blue force element (n) position compromised
Blue	IN_20.0		//Mission execution timeline has changed//
		1	Mission timeline is not as planned
		2	Mission timeline is not as expected
Blue	In_21.0		//Route to objective is no longer valid/tenable//
		1	Squad Ingress route to objective no loner valid

SubType	Phase		Information Requirements During Objective Phase
Blue	Obj_1.0		//Unit mission navigation warning//
		1	Unit Squad(n)/Rifleman(n) is not in planned position
		2	Unit Squad(n)/ Rifleman is not in expected position
		3	Unit/Squad(n) time to pre-assault position is delayed by "x" minutes
Blue	Obj_2.0		//Intelligence, Surveillance, Reconaisance (ISR) of target area//
		1	UAV does not have video/sensor observation of target area
		2	Recon element has not confirmed HVT position
		3	Recon element has lost visual contact with blue squad(n)
Blue	Obj_3.0		//Location of msn essential organic blue force maneuver elements, in this case a 12 man squad.//
		1	Actual position of Squad(n) is not as planned
		2	Actual position of Squad(n) is not as expected
Blue	Obj_4.0		//Status of organic blue force critical weapon systems//
		1	# of critical organic blue force weapon systems nonoperational exceeds Go-No-Go criteria.
Blue	Obj_5.0		//Communication device effective range limt being reached//
		1	Organic blue force member's peer to peer com device approaching link range limit.
		2	Organic blue force member's peer to peer com device has exceeded effective com link range limit.
Blue	Obj_6.0		//Communication device approaching voice/video/data threshold capability
		1	Comm device data throughput [data rate?] approaching video threshold
		2	Comm device data throughput [data rate?] approaching data threshold
		3	Comm device data throughput [data rate?] approaching voice threshold
Blue	Obj_7.0		//Comm system's power available exceeded//
		1	Comm device power available threshold exceeded
Blue	Obj_8.0		//Enemy size has changed//
		1	Current enemy size not as planned
		2	Current enemy size not as expected
Red	Obj_9.0		//Enemy unit's weapon system employed has changed.//
		1	Enemy unit's weapon system not as planned
		2	Enemy unit's weapon system not as expected
Red	Obj_10.0		//Enemy unit's C4ISR capability//
		1	Enemy unit's ISR capability not as planned
		2	Enemy units's C2 capability not as planned
Red	Obj_11.0		//enemy RF communications threshold status used as an indicator and warning (I&W)//
		1	Enemy unit comm traffic exceeds normal parameters
Blue	Obj_12.0		//Position/status of blue force recon element//
		1	Blue force organic recon element (n) current position not as planned
		2	Blue force organic recon element (n) current position not as expected
		3	Blue force organic recon element(n) position comprimised



NAVAL
POSTGRADUATE
SCHOOL

Enabling Adaptive C2 via Semantic Communication and Smart Push: A Model-based Network Communication Approach

LtCol Carl Oros, USMC

Brief to

13th ICCRTS: *C2 for Complex Endeavors*
The Meydenbauer Center
Bellevue, WA
17 June 2008

The Nation's Premier Defense Research University

Monterey, California
WWW.NPS.EDU

The Literature: Self-Synchronization and Shared Awareness

Desired Agile C2 Attributes

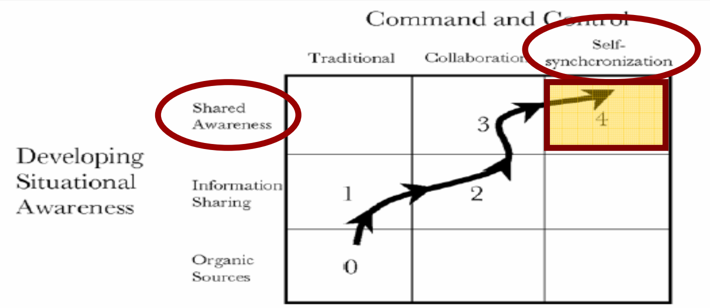


Figure 13. NCW Maturity Model[5]
From Power to the Edge

NCW is characterized by the ability of geographically dispersed forces (consisting of entities) to create a high level of ***shared battlespace awareness*** *that can be exploited via self- synchronization and other network-centric operations to achieve commanders' intent.* (Network Centric Warfare, 1999)

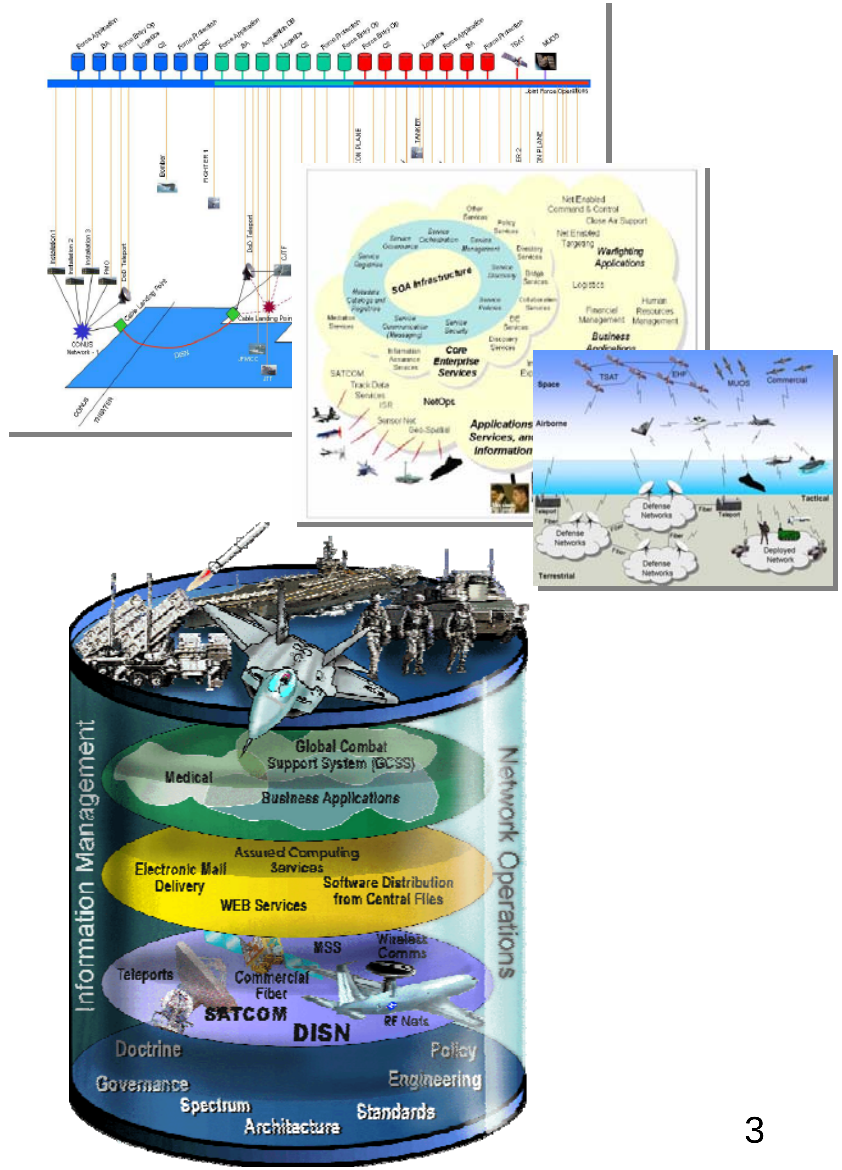
The ability to self-synchronize requires a ***rich shared understanding across the contributing elements****.* (Planning Complex Endeavors)

New approaches to both command and control are necessitated amongst other things by (1) a need to accommodate the realities of complex operations such as coalition and civil-military operations and ***(2) a desire to increase awareness and leverage shared awareness across a large, distributed enterprise consisting of many different kinds of participants.*** (Planning Complex Endeavors)

The Future

The GIG will support and enable highly responsive, agile, adaptable, and information-centric operations characterized by:

- An increased ability to share information
- Greatly expanded sources and forms of information and related expertise to support rapid, collaborative decision-making
- Highly flexible, dynamic, and interoperable communications, computing, and information infrastructures that are responsive to rapidly changing operational needs
- Assurance and trust that the right information to accomplish assigned tasks is available when and where needed, that the information is correct, and that the infrastructure is available and protected



Source: DoD GIG Architecture Vision 1.0 Jun 07, p. 2.

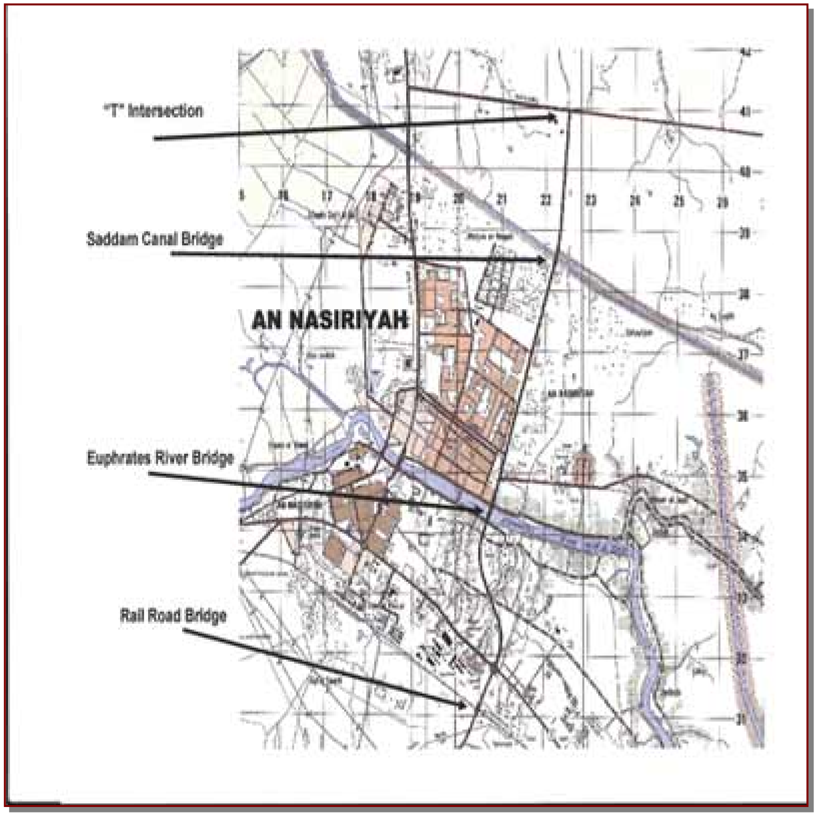
The Reality:
The Battle for An Nasiriyah 2003*

*"The command group had **little situational awareness (SA)** outside of the three city blocks it occupied.."*

*"The simultaneous engagements, urban terrain, and distances separating individual companies were **wreaking havoc on the Com. network.** "*

"Information that would normally come to the command group and be passed to the battalion commander and operations officer suffered delay and distortion through second-, third-, and fourth-party relays. Attempts by the command group to raise the battalion commander on radio only added to the congestion and were quickly abandoned. "

Task Force Tarawa



•Rohr, Karl.C., "*Fighting Through the Fog of War", Marine Corps Gazette, 2006, available:* *http://www.mca-marines.org/Gazette/2006/06rohr.html*

The Reality: The Battle for An Nasiriyah, 23 March 2003*

- *"fires could only be in his zone against targets visually identified as enemy"*
- *"a firefight of this nature will have difficulty tracking other friendly forces operating nearby but out of sight."*
- *"Some aircraft did not have the ability to communicate with the FSCC"*
- *"With communications disrupted, the air officer was not able to coordinate the flow of aircraft."*
- *"(FACs) had to build the pilots' SA and do weaponeering as the aircraft checked in"*

•Rohr, Karl.C., "*Fighting Through the Fog of War", Marine Corps Gazette, 2006, available:* http://www.mca-marines.org/Gazette/2006/06rohr.html

Challenges: The Evolving Environment

- Traditional force structures (Battalions, Companies) are being forced to disperse and operate on vast frontages & in urban settings
  - A traditional battalion frontage is 1 -2 Km
  - Today, certain units are operating in over 3600 sq. mile area, controlling over 20 battle positions, and monitoring over 70 coalition positions
- The nature of the threat has
  - Increased the need for precision targeting
  - Forced the dispersion of forces, both in urban and in rural environs
  - Placed a high demand on the *infostructure* for focused information and actionable intelligence

Challenges: System Bandwidth

- Physical bandwidth and available spectrum are limited resources
  - FCS BW demand 10 x > Army capability
    - 43M lines of code (exceeds JSF program as #1)*

    Source: Congressional Budget Office Study, "The Army's Bandwidth Bottleneck", 2003.
  - A typical USMC MEF is doctrinally provisioned 2 Mbps for a corps sized force
    - BW demand will increase as computer systems migrate to lower tactical echelons (Battalion and below)

Challenges: Cognitive Bandwidth

- Human bandwidth is fixed
  - *InfoGlut* (Denning): Computer generated information capabilities vastly exceed human info processing ability
  - Increases in System BW capability (broadband) exacerbates the problem: more data is transmitted to the user
    - A UAV has the potential to generate terabytes of data/hour.
    - 14,000 UAV hrs/month typical = petabytes (10^{15}) monthly/exabytes (10^{18}) yearly for these systems alone.
      - AKA: *Digital Landfills* (Gen Tom Hobbins, USAF)
  - Service Oriented Architectures (SOA) & Data tagging will "unearth" more searchable data and further compound the problem

The Resultant Dilemma: InfoGlut

- Potential to overload the operator with *bits*, as we have with *molecules*

NAVAL POSTGRADUATE SCHOOL

The Recommended Solution

- Shannon is not enough
  - Shared awareness cannot be attained through physical bandwidth alone (i.e. “pipes”)
  - Bandwidth for mobile entities will always be in high demand
  - User bandwidth is fixed
- Substantially reduce bit flow by only transmitting significant bits
- How?
  - Equip entities/actors with a shared, stateful model (the “kernel”)
  - Transmit the “deltas” of these models when user defined conditions warrant it

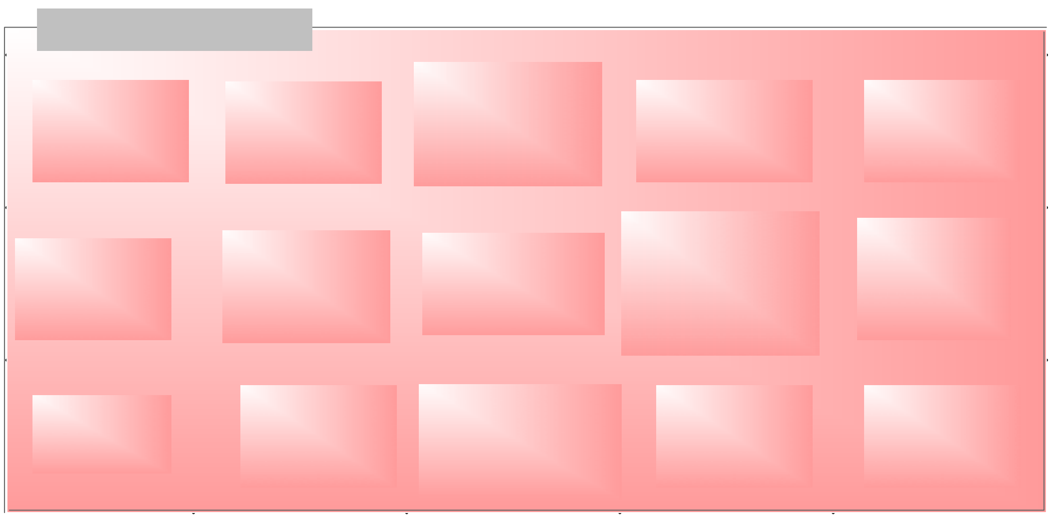
MCN-VIRT: Doing More with *Less*

- Communicate significant bits
  - Maintain a shared understanding of the dynamic situation
    - Agree upon *semantics*
    - Distribute a stateful, meaningful model
    - Filter bits by *value* & *push* them to the operator
- Implication
  - Decrease required BW (transmit “deltas” of the model
  - Increase available cognitive BW (reduce glut)

An Operationalized World Model

Model: A collection of our plans, assumptions, beliefs, and intent

i.e. …



– Today this model is instantiated in our:
  - Plans: OPLANs, CONPLANs, OPORDs, FRAGOs, mission orders, Air Tasking Order (ATO), terrain models, maps
  - Select Systems: Theater Battle Management Corps System (TBMCS), Global C2 System (GCCS), C2PC/FBCB2, limited mission systems

– Carried into battle by humans on maps, knee-board cards, Microsoft Office products, Face-2-Face briefs and in memory

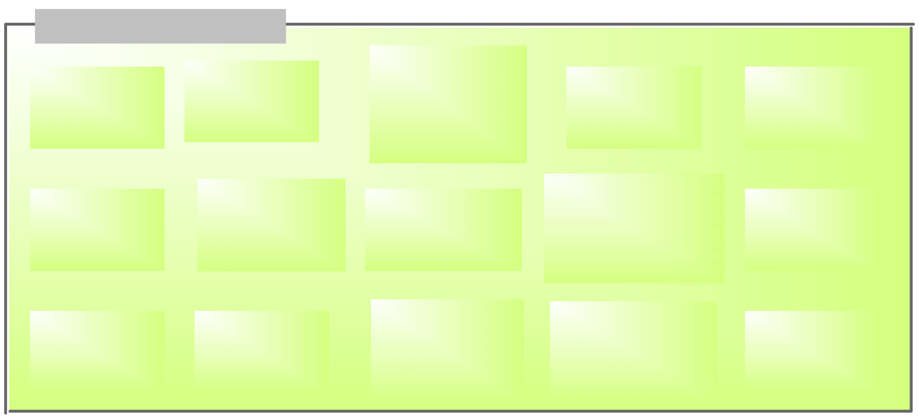
Today: Distributing the Battlefield Model

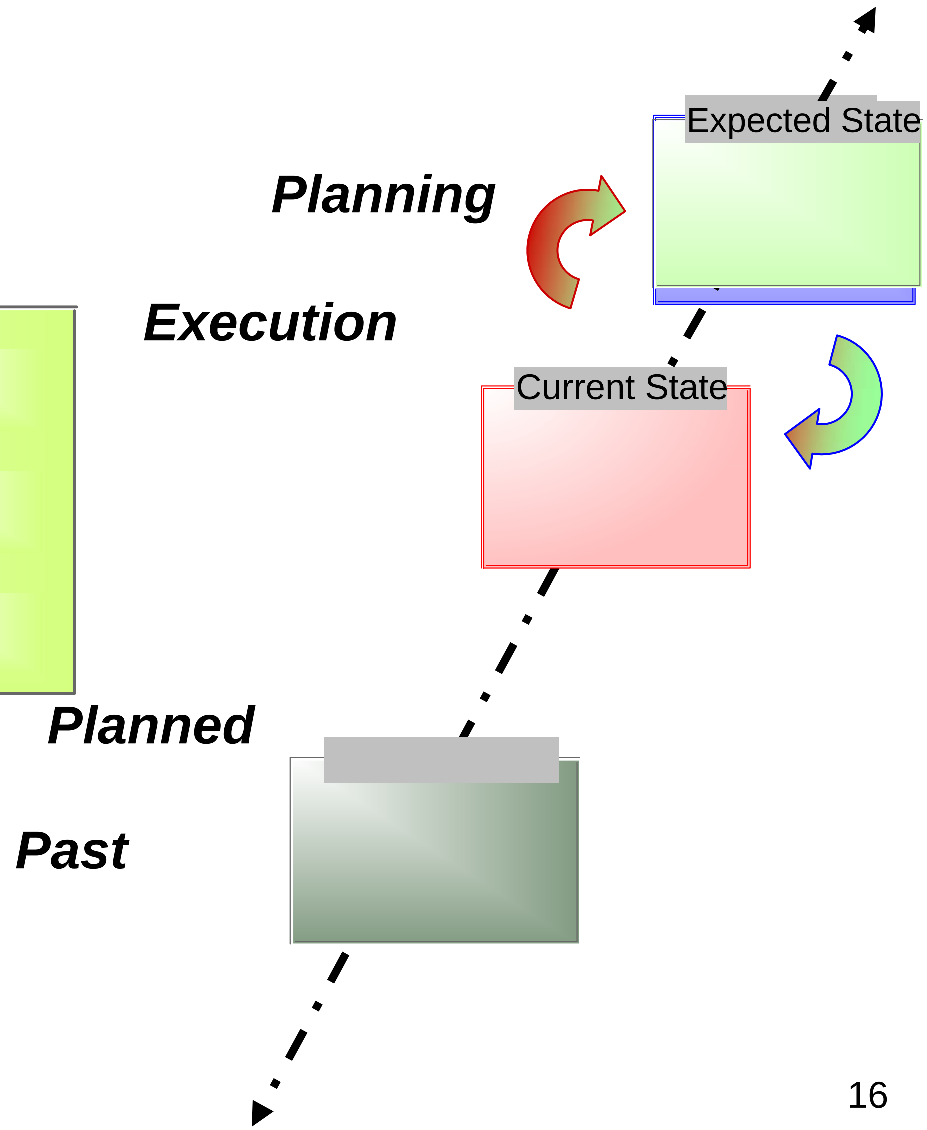
Today: Distributing the Battlefield Model

Today:
Distributing the Battlefield Model

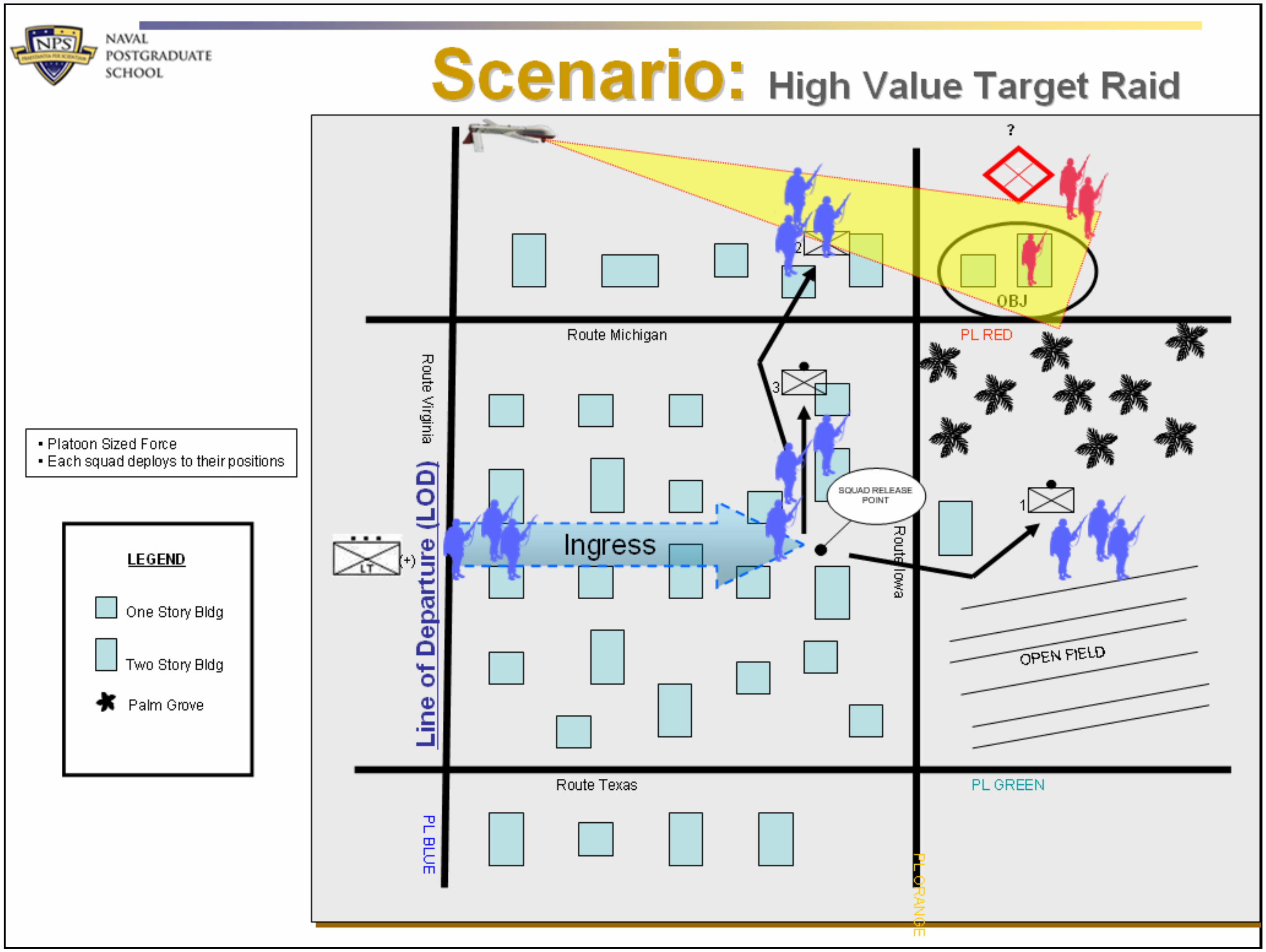
A Stateful World Model Example

A dynamic model indexed in time





Mission Thread HVT Scenario



NAVAL POSTGRADUATE SCHOOL

Discovering Conditions of Interest

NAVAL POSTGRADUATE SCHOOL

Conditions of Interest

1-1. Notify me if my target location is no longer valid.

1-1.a. The distance we are concerned with is a variable. For this instance, we say +/- 100m

1-2-1. Tell me if there are any of friendly organic forces injured to the extent that it impacts mission accomplishment.

1-2-1.a. Variable here is the definition of what hinders the mission. Examples include mobility, life threatening injuries, and combat effectiveness issues.

1-2-2. Same as 1-1. Variable here is the distance of the squad from it's expected location; We are concerned with +/- 50m.

1-2-3. Tell me if any organic blue force weapons become inoperable.

1-2-3a. By inoperable, we mean incapable of sending a round downrange. Does not take into account multiple weapon systems (203 grenade launcher)

Target location known	*Actual Target location not as planned / expected*
All organic blue forces are mission capable	*Organic blue force casualties exceeds Go-No-Go threshold*
Squads' locations are accurate	*Squads' locations are not as planned / expected*
Weapons are mission capable	*# non-mission capable Weapon systems exceeds Go-No-Go threshold*
Still within my communication's threshold	*Approaching my communication device's threshold*

Formalizing Valuable Information: Conditions of Interest

NAVAL POSTGRADUATE SCHOOL

Example Information Requirements and Conditions of Interest (COIs)

In_1.0 **//Target Location has changed//**

1 **Current target location not as planned**

[Mission]: Msn_#, Msn_Type-HVT,[Phase]:= Ingress, [Target]:Tgt_ID, [Location]: Location_ID, Coordinates ≠ Coordinates Planned

2 **Current target location not as expected**

[Mission]: Msn_#, Msn_Type-HVT,[Phase]:= Ingress, [Target]:Tgt_ID, [Location]: Location_ID, Coordinates ≠ Coordinates Expected

In_2.0 **//Health & status of organic, mission assigned, friendly forces//**

1 **Blue organic force member is seriously injured**

[Mission]: Msn_#, Msn_Type-HVT,[Phase]:= Ingress, [Rifleman]: Rifleman_ID **and/or** [Squad]: Sqd_Ldr **and /or** [Fire_Team]: FireTeam_Ldr, Health_N_Status = Serious Injury

2 **# of organic blue forces injured exceeds mission Go-No-Go criteria**

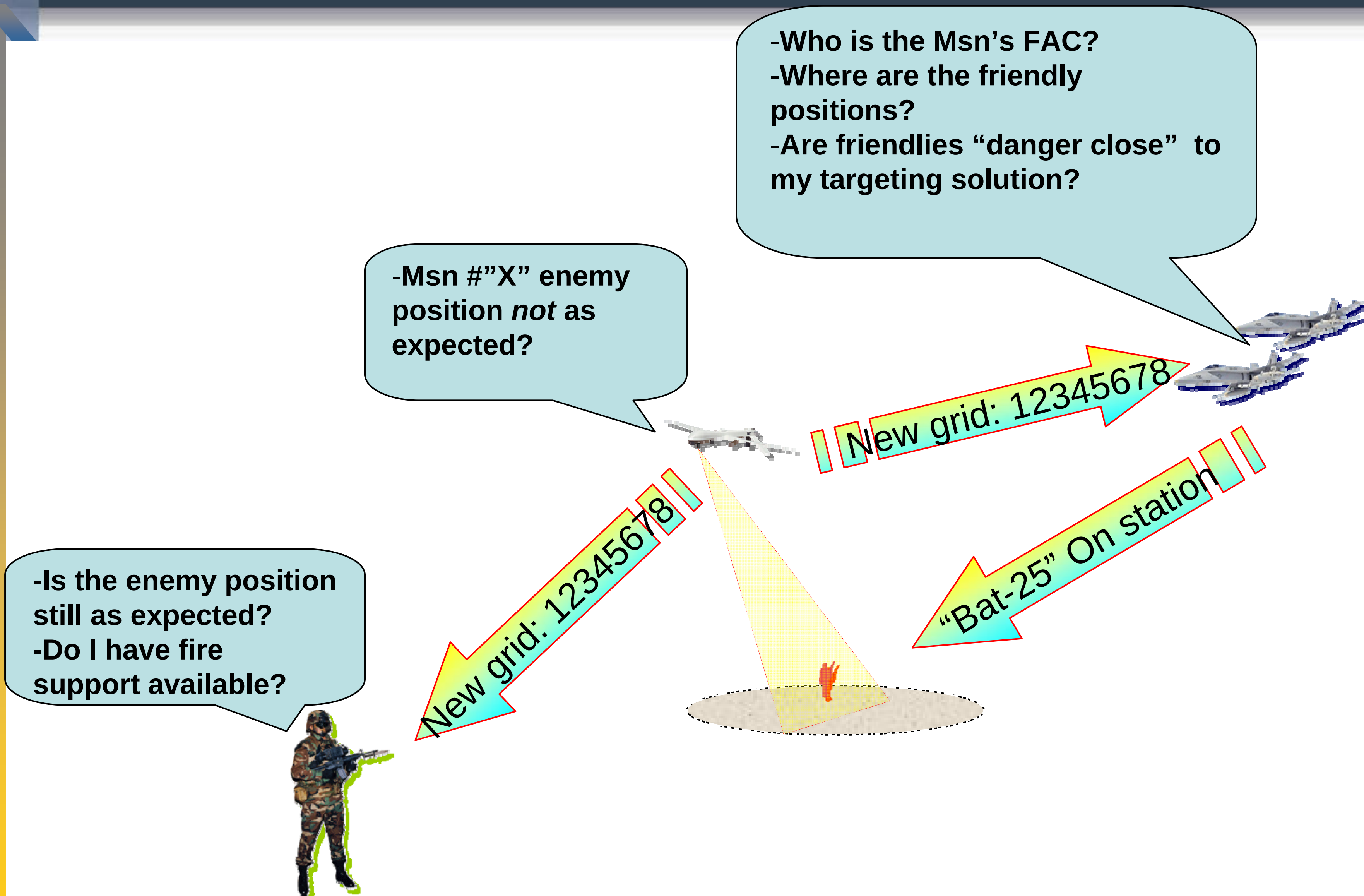
[Mission]: Msn_#, Msn_Type-HVT,[Phase]:= Ingress, [Rifleman]: Rifleman_ID **and/or** [Squad]: Sqd_Ldr **and /or** [Fire_Team]: FireTeam_Ldr, Health_N_Status **SUM Qty** Serious Injury ≥ **Go_No_Go_Criteria {abort}**

In_3.0 **//Location of msn essential organic blue force maneuver elements, in this case a 12 man squad.//**

1 **Current position of Squad(n) is not as planned**

[Mission]: Msn_#, Msn_Type-HVT,[Phase]:= Ingress, [Squad]:Squad_ID, [Location]: Location_ID, Coordinates ≠ Coordinates Planned

User Defined Conditions of Interest and *Smart Push*



Take Away

MCN-VIRT:

- Reduces InfoGlut by conserving Physical and Human bandwidth
- All actors/entities share a dynamic, semantic model at its core
- Communicates significant bits
  - Pushes valuable bits to the operators when user defined conditions of interest (COIs) emerge
- Promotes C2 agility/self-synchronization by distributing a shared, stateful, operational model

Questions?

Back up

VIRT/MCN Defined

- *A Model-based Communication Network (MCN) is a state-full distributed system of collaborating nodes that maintains an optimal shared understanding of the situation.*
  - *The situation at each node is composed of models of all entities relevant to its mission*
  - *Understands the state of its collaborating nodes*
    - *Including missions, assumptions, and beliefs*

- VIRT: Services that deliver *valued information at the right time to* MCNs
  - VIRT services filter information so high value bits are prioritized and low value bits are depreciated

Semantic Object Model

NAVAL POSTGRADUATE SCHOOL

USMC-VIRT Semantic Object Model v.1

Concepts of…